Argonne NATIONAL LABORATORY

Wireless RF Readout of Large Detectors

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-LDRD proposal "Development of Wireless Data and Power Transfer Techniques for Large Instrumentation Systems" → Funded FY 2010.

Motivation

Problem

-With the detectors increasing in its size and complexity it is complication to use traditional approach where the signal and the power are distributed with electric cables.

-Cabling may represent a significant cost and complication in experiments.

Approach

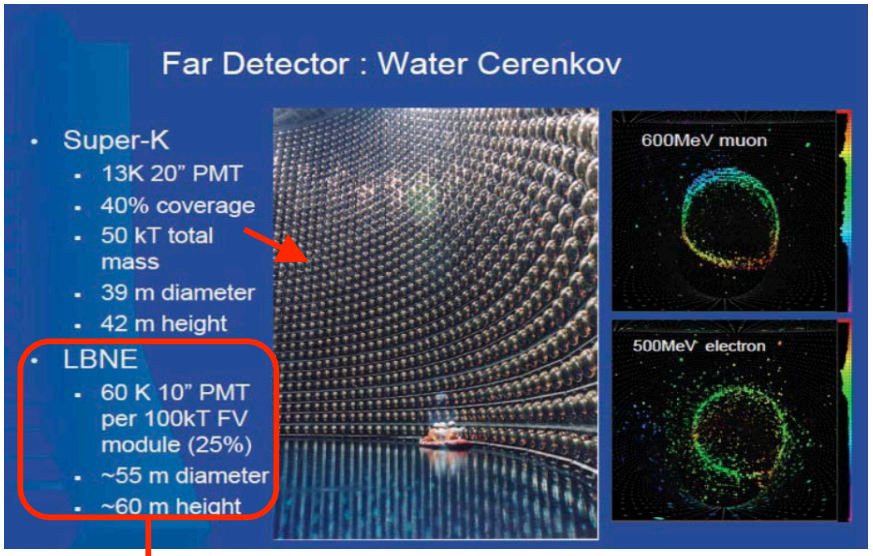
-Proposal has two components, to be addressed:

-data transfer (RF technology)→current effort

-power transfer (possible optical beam)

Goal

-Elimination of all cables: no physical connection to the detector.



Example: LBNE FEE Requirements and how to meet them?

From Volume 4: Water Cherenkov Detectors https://wiki.bnl.gov/dusel/index.php/CDR

Parameter	Value	Notes
Total PMT count	50,000	
PMTs per rack	512	
PMT Dark Noise Rate	10 kHz	Very conservative
Bytes per hit	8 bytes	32 bits time, 16 bits channel no., 16 bits charge

Table 4.4. Assumptions used for data rate and volume estimates.

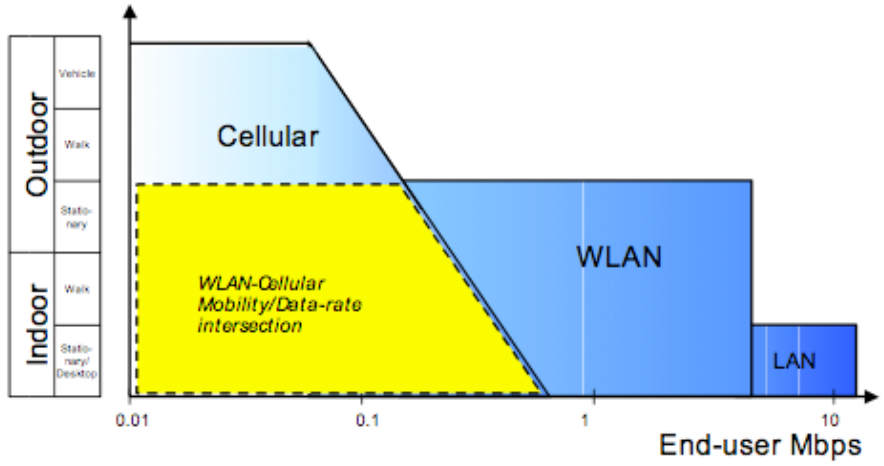
-expected average data rate for a single channel is ~480 kbps (time+charge).
-challenge for this application is the 24 Gbps total data rate from the whole detector (~50000 PMTs).
-data rate achievable from individual channel with several conventional (commercial cheap RF/cell-phone/WiFi tech.) wireless technologies.
-technology exists but never used with a high channel count.
-two subsets of wireless technologies were studied for feasibility of use for large instrumentation applications:
  -mobile/cellular technologies (GPRS, UMTS, CDMA/EVDO Rev.A, WiMAX, LTE)
  -wireless local area network technologies (802.11x, Bluetooth, Zigbee, etc.).

Wireless Data Transmission Methods

-Local Area Network vs Mobile Network:

We evaluated existing networking technologies and explored the feasibility of using them in instrumentation applications.

-LANs offer high access data rates, but provide limited coverage, whereas cellular mobile networks such as GPRS and UMTS offer widespread coverage at lower data rates.



WLAN vs. cellular properties

	WLAN	Cellular
Coverage	Hotspots, primarily indoors	Scalable to nation-wide coverage
Spectrum	Unlicensed (ISM)	Licensed
User data rates	Up to several Mbps	~20-500 kbps
QoS	Best effort, load sensitive	Planned and managed. Guaranteed QoS possible.
Mobility	Nomadic. Possibly also session continuity with Mobile IP	Full mobility. Seamless service.
System cost	Low cost. Low entry barriers.	High cost. High entry barriers.
Pricing schemes	Free / bundled / one off / prepaid	Telco model (prepaid / postpaid, etc...)

We need:

-high data rates and limited range between sources and access point.

We don't need:

-mobility of sources wrt access point.

Approach for this R&D

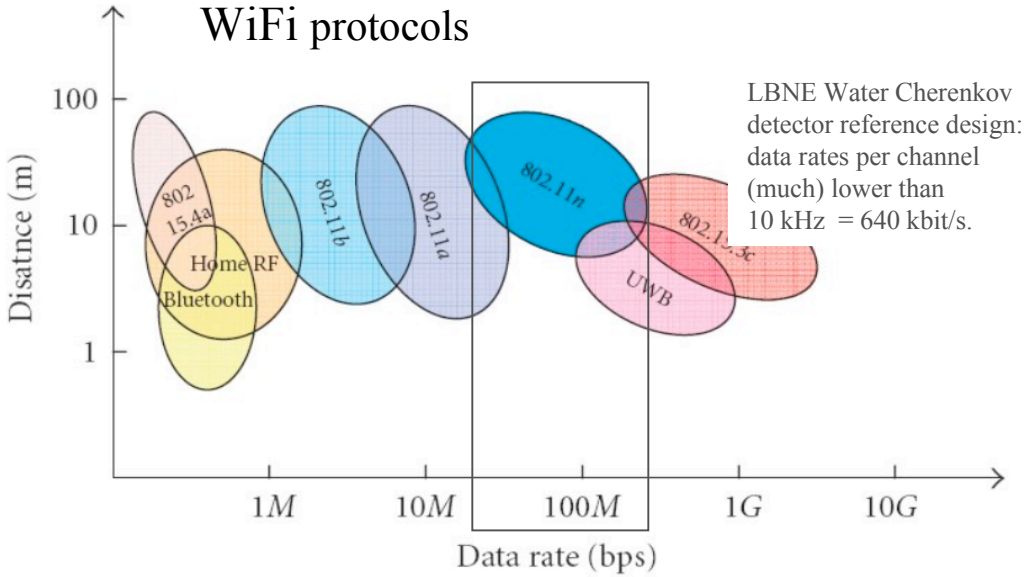
-Choose LANs over Mobile Network.

-IEEE 802.11 is a set of standards for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6 and 5 GHz frequency bands.

-Created and maintained by the IEEE LAN/MAN Standards Committee (IEEE 802).

-802.11n is an amendment which improves upon the previous 802.11 standards by adding multiple-input multiple-output antennas (MIMO).

-802.11n operates on both the 2.4 GHz and the lesser used 5 GHz bands.



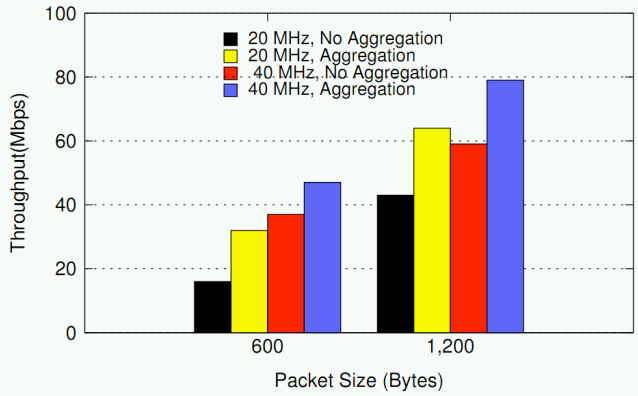


Figure 3: Average throughput achieved on a isolated 802.11n link under different combinations of channel width and aggregation mechanisms.

802.11n Standards

2.4 GHz
72 MHz total bandwidth

channel	frequency (MHz)	North America [3]	Japan[3]	Most of world[A] [3][4][5][6][7]
1	2412	Yes	Yes	Yes
2	2417	Yes	Yes	Yes
3	2422	Yes	Yes	Yes
4	2427	Yes	Yes	Yes
5	2432	Yes	Yes	Yes
6	2437	Yes	Yes	Yes
7	2442	Yes	Yes	Yes
8	2447	Yes	Yes	Yes
9	2452	Yes	Yes	Yes
10	2457	Yes	Yes	Yes
11	2462	Yes	Yes	Yes
12	2467	No[B]	Yes	Yes
13	2472	No[B]	Yes	Yes
14	2484	No	11b only[C]	No

5 GHz
1165 MHz total bandwidth

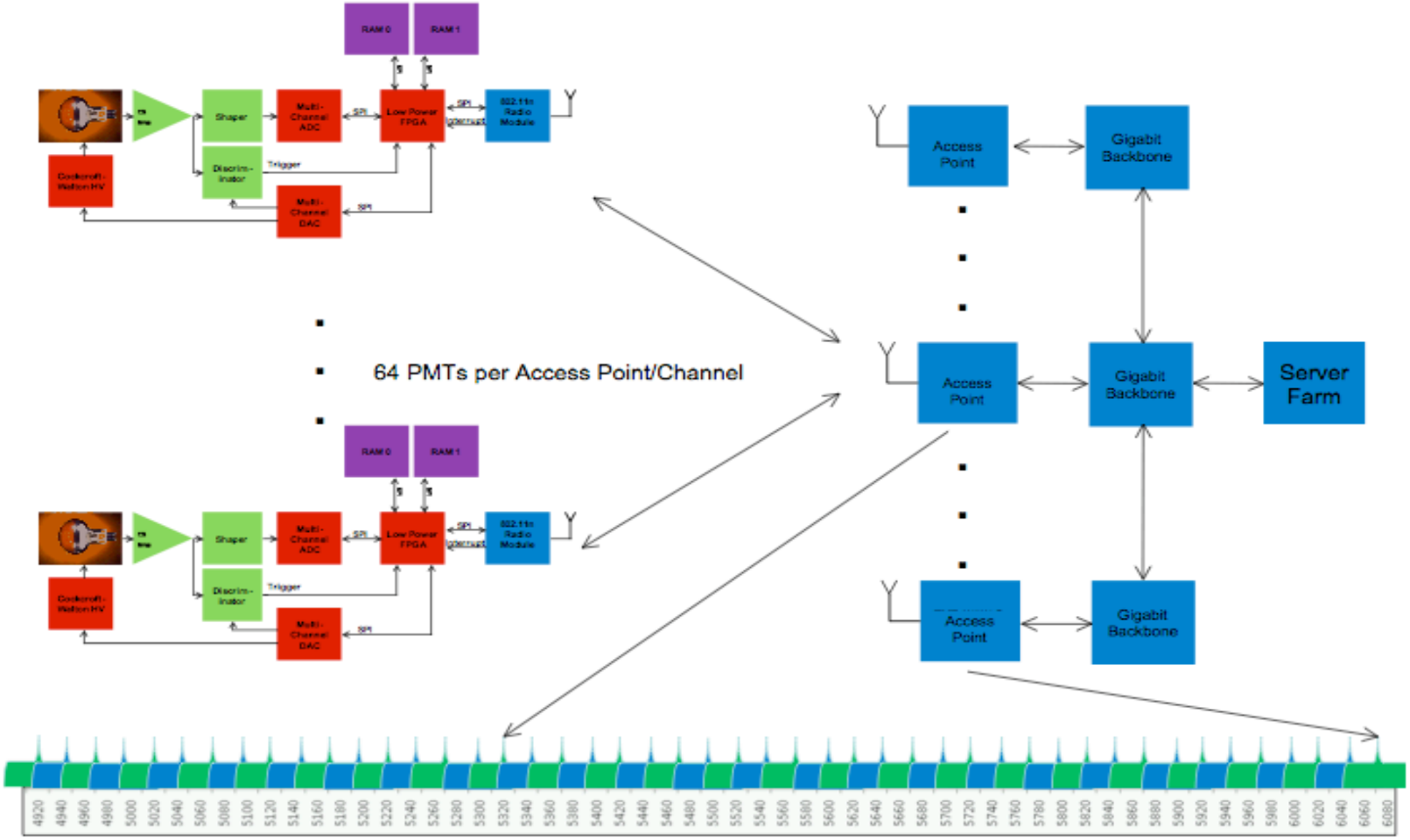
channel	frequency (MHz)	United States	Europe	Japan		Singapore	China	Israel	Korea	Turkey
		40/20 MHz[12]	40/20 MHz	40/20 MHz[13]	10 MHz	20 MHz	20 MHz	20 MHz[6]	20 MHz[14]	20 MHz
183	4915	No	No	No	Yes	No	No	No	No	No
184	4920	No	No	Yes	Yes	No	No	No	No	No
185	4925	No	No	No	Yes	No	No	No	No	No
187	4935	No	No	No	Yes	No	No	No	No	No
188	4940	No	No	Yes	Yes	No	No	No	No	No
189	4945	No	No	No	Yes	No	No	No	No	No
192	4960	No	No	Yes	No	No	No	No	No	No
196	4980	No	No	Yes	No	No	No	No	No	No
7	5035	No	No	No	Yes	No	No	No	No	No
8	5040	No	No	No	Yes	No	No	No	No	No
9	5045	No	No	No	Yes	No	No	No	No	No
11	5055	No	No	No	Yes	No	No	No	No	No
12	5060	No	No	No	No	No	No	No	No	No
16	5080	No	No	No	No	No	No	No	No	No
34	5170	No	No	No	No	No	No	Yes	Yes	Yes
36	5180	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
38	5190	No	No	No	No	No	No	Yes	Yes	Yes
40	5200	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
42	5210	No	No	No	No	No	No	Yes	Yes	Yes
44	5220	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
46	5230	No	No	No	No	No	No	Yes	Yes	Yes
48	5240	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
52	5260	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
56	5280	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
60	5300	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
64	5320	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
100	5500	Yes[15]	Yes	Yes	No	No	No	No	Yes	No
104	5520	Yes[15]	Yes	Yes	No	No	No	No	Yes	No
108	5540	Yes[15]	Yes	Yes	No	No	No	No	Yes	No
112	5560	Yes[15]	Yes	Yes	No	No	No	No	Yes	No
116	5580	Yes[15]	Yes	Yes	No	No	No	No	Yes	No
120	5600	No[15]	Yes	Yes	No	No	No	No	Yes	No
124	5620	No[15]	Yes	Yes	No	No	No	No	Yes	No
128	5640	No[15]	Yes	Yes	No	No	No	No	Yes	No
132	5660	No[15]	Yes	Yes	No	No	No	No	No	No
136	5680	Yes[15]	Yes	Yes	No	No	No	No	No	No
140	5700	Yes[15]	No	Yes	No	No	No	No	No	No
149	5745	Yes	No	No	No	Yes	Yes	No	Yes	Yes
153	5765	Yes	No	No	No	Yes	Yes	No	Yes	Yes
157	5785	Yes	No	No	No	Yes	Yes	No	Yes	Yes
161	5805	Yes	No	No	No	Yes	Yes	No	Yes	Yes
165	5825	Yes	No	No	No	Yes	Yes	No	Yes	Yes

802.11x 2.4 and 5 GHz frequency/channel spectrums (5 and 20 MHz channel widths in 2.4 and 5GHz respectively).

System Design

-PMT base block diagram (many channel = LBNE).

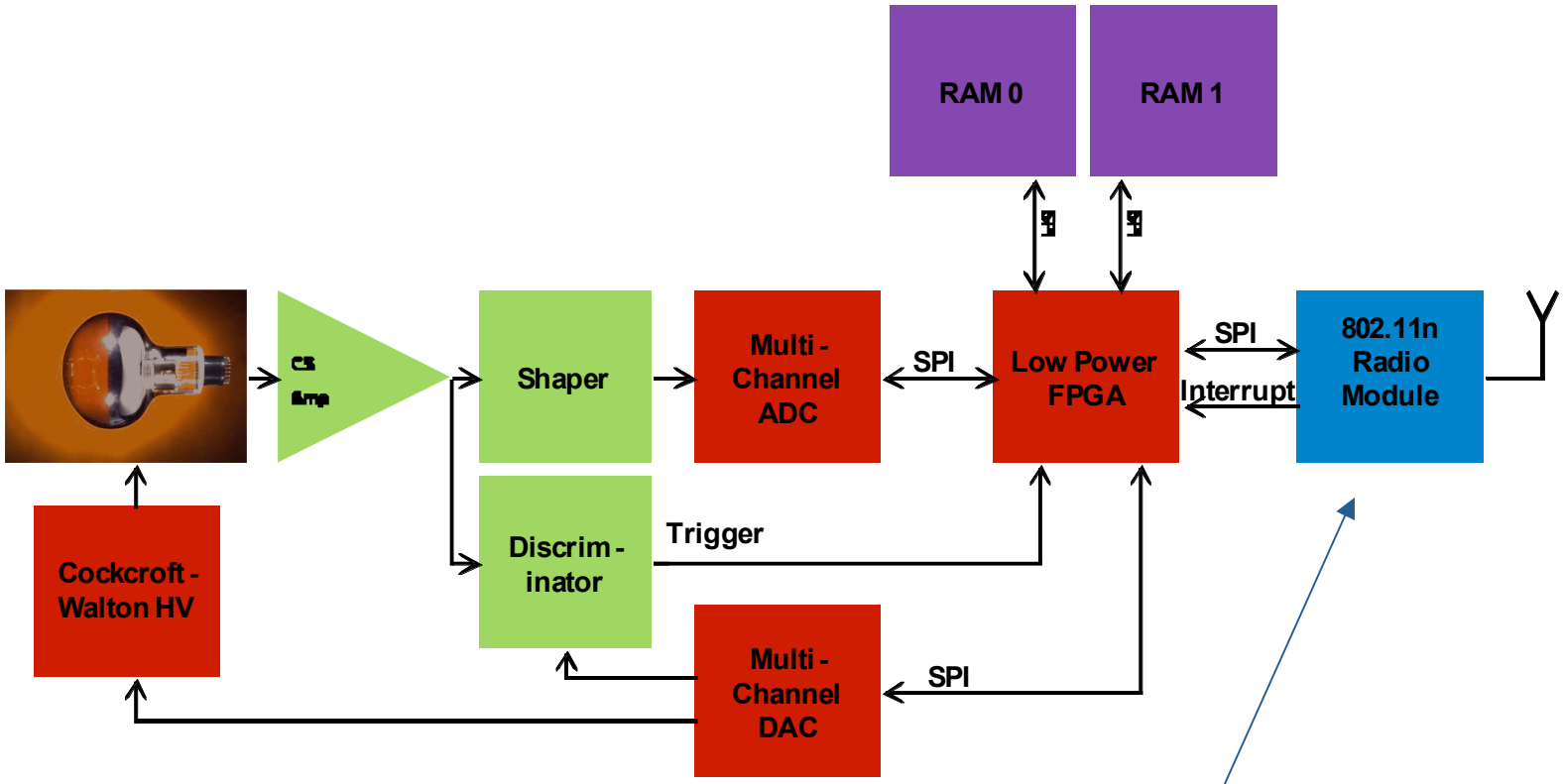
-The system consists of many access points (~48) each communicating to many clients (~64), for a total of 3072 clients.



-LBNE Large Instrument Wireless Readout Schematic: 48 Access Points per sector x 35 Mbit/s per Access Point = 1.68 Gbit/s per sector.

System Design

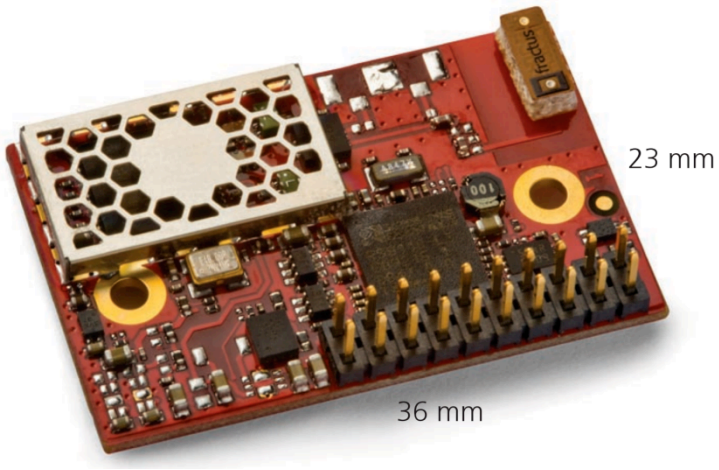
-Single stream 802.11n access points have an individual operating bandwidth of 20 MHz.
-Possible to populate up to 48 access points within the usable 1 GHz frequency spectrum.
-This spectrum translates into a total payload data rate of 1.68 gigabits/s.
-Single access point will be implemented in the PMT base:

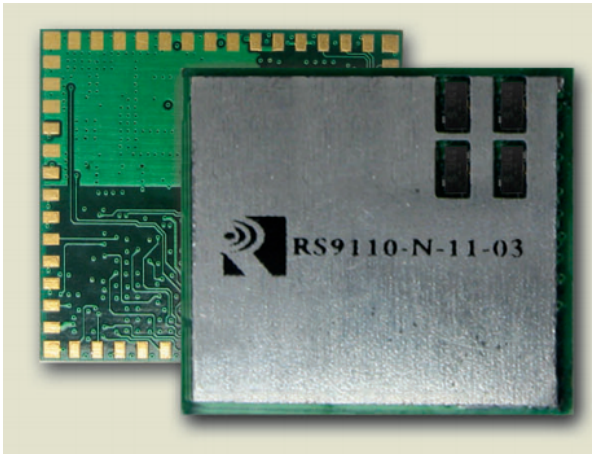


-Core of the current scheme is an ultra-low power dual-band 802.11n module built by ConnectBlue.

Ultra Low Power Dualband 802.11n Module RS9110-N-11-03

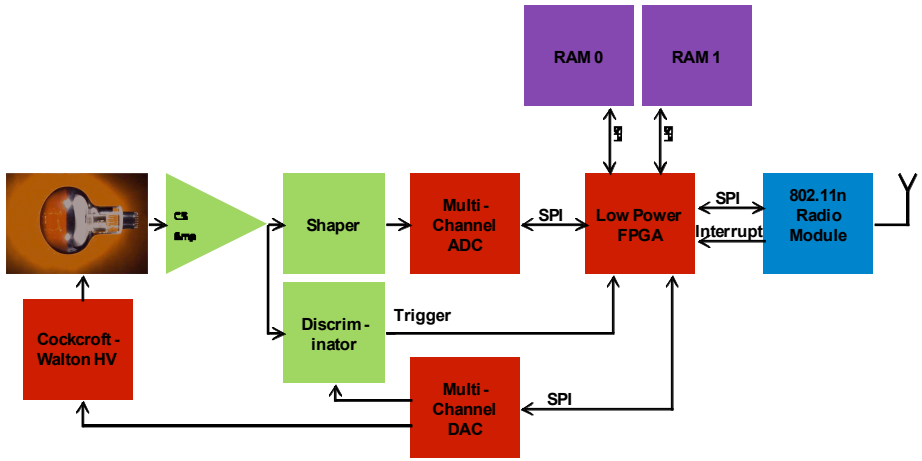
-Manufacturer: Redpine Signals.
-The RS9110-N-11-03 module is an IEEE802.11abgn Wi-Fi client device with an integrated MAC, BBP, RF transceiver and PA.
-end-to-end solution for ultra low power WLAN applications.





-Data Rate 802.11n: 65 Mbps (payload data rate 35Mbps)
-Frequency Band2.412 - 2.484 GHz and 4.900 - 5.925 GHz
-Supply Voltage3.1 – 3.6 V
-Relatively simple integration for our prototype unit and possibly beyond.

Prototype Development



-We have established technical contacts at ConnectBlue and Redpine Signals and have established nondisclosure agreements with both companies.

-will be releasing low-power MIMO based modules: go beyond the single-stream data rate limitations.

-The current design uses a Xilinx FPGA which consumes far more power than what we ultimately intended to build.

-Future designs will be developed around lower power solutions.

Current Status and Next Steps

-LDRD funded. $179550 allocated for FY2011. Expect renewal funding in FY2012.

-In the first six months of the LDRD R&D (October 1st 2010 – April 1st 2011) we:

-evaluated existing RF devices,

-developed a conceptual design of an RF-based data acquisition system for a large experiment or another application.

-The current and future effort in this fiscal year (2010) is the following:

-build a prototype of a front-end channel that incorporates the requisite technology, attempting the low-power requirements.

-design a small network of three clients and a single access point (current effort).

-evaluate performance of the system: carrier frequencies, transmission data rates (i.e. bandwidth), source to receiver distances, and power consumption.

-The effort planned for the next fiscal year (2011) is the following:

-test extrapolation to a large system with multiple clients and access points, with tests of variable data rates, channel widths. Simulations of data transfer rates, errors and error correction, and pile-up.

-address the power transfer.

Conclusion

-This proposal aims at new developments in high speed data acquisition system in high energy physics with goal of eliminating cables in large systems.

-This technology has the potential to significantly reduce the cost and complexity of the infrastructure needed for the instrumentation of future experiments

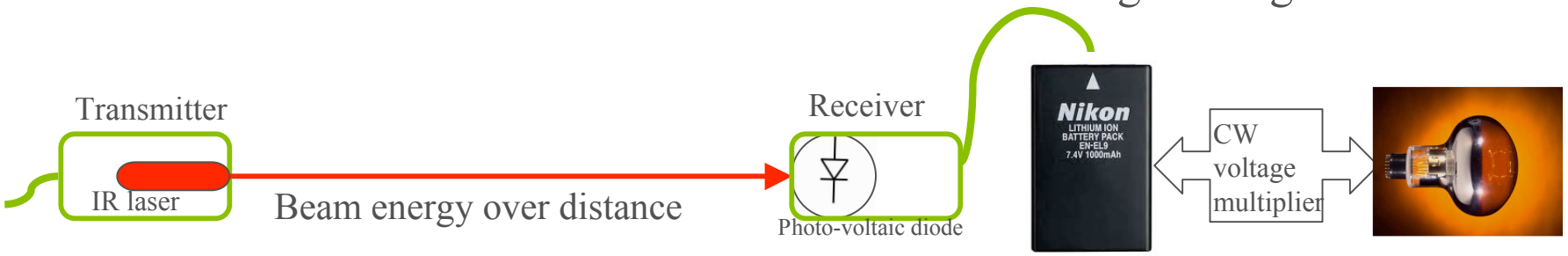
- -such as LBNE, for example
- -field applications such as monitoring of neutrino flux at nuclear reactor (non-proliferation).
- -potential security applications.

-Have written an Early Career grant proposal "Development of Data and Power Transfer Techniques for Large Neutrino Detector" → Submitted to DOE in November 2010, not funded.

Backups

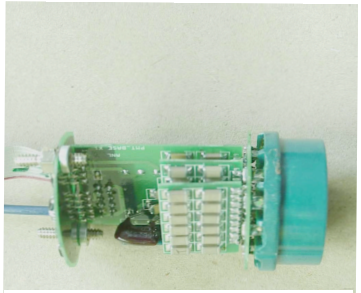
Power Transfer

-Transmission over distance and conversion from a low to high voltage to run PMT.



Conversion from few to ~1000V

-Use Infra Red laser diodes to turn the electricity into optical, then detect with photodiodes. Similar to a solar cell but higher efficiency.
-Recharge the battery.
-Use Cockcroft-Walton in PMT base converts the low-voltage to high voltage needed for PMTs (~1000 V).



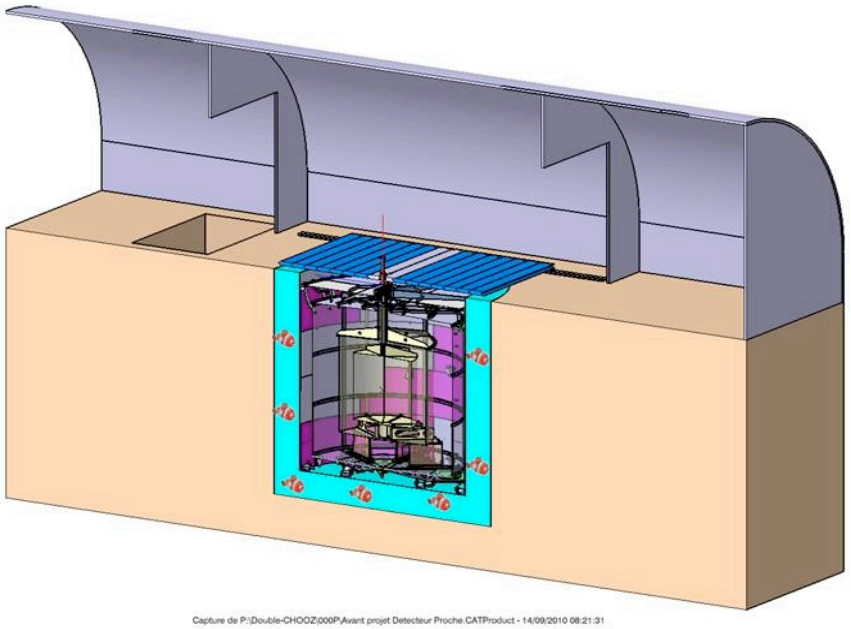
HEP designed Cockcroft-Walton base for ZEUS Experiment.

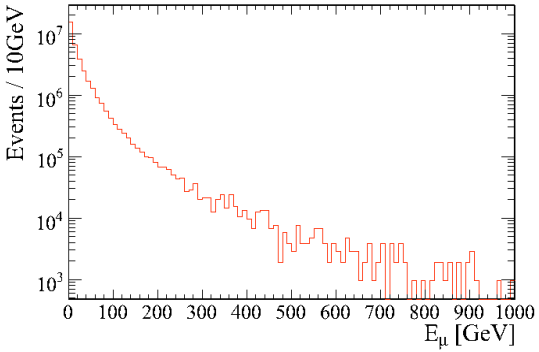
Plan:

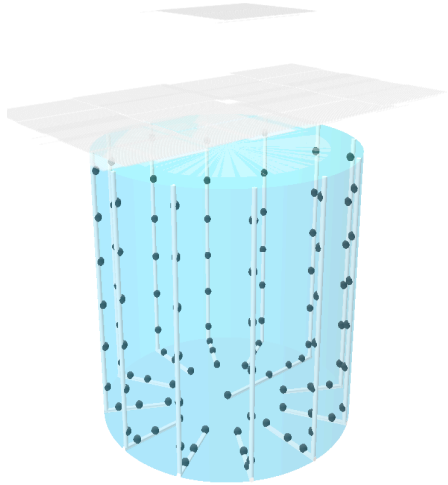
-Construct a prototype with a single channel that runs PMT continuously.
-Construct a demonstrator with a reasonable load and several channels to demonstrate potential for a remote application.
-Connected to ANL battery and photo-voltaics experts.

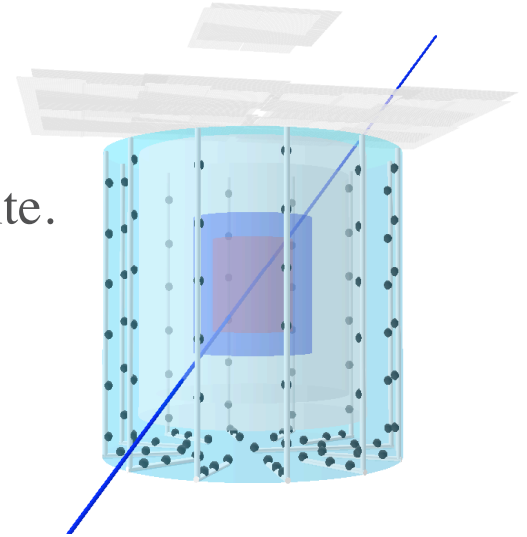
Expand ideas to Early Career grant proposal

-Consider both traditional approach (cables) for novel techniques (wireless) for data and power transfer.
-Primary focus is Water Cherenkov detector in the LBNE experiment.
-Make advantage of "existing" infrastructure and our involvement in Double Chooz



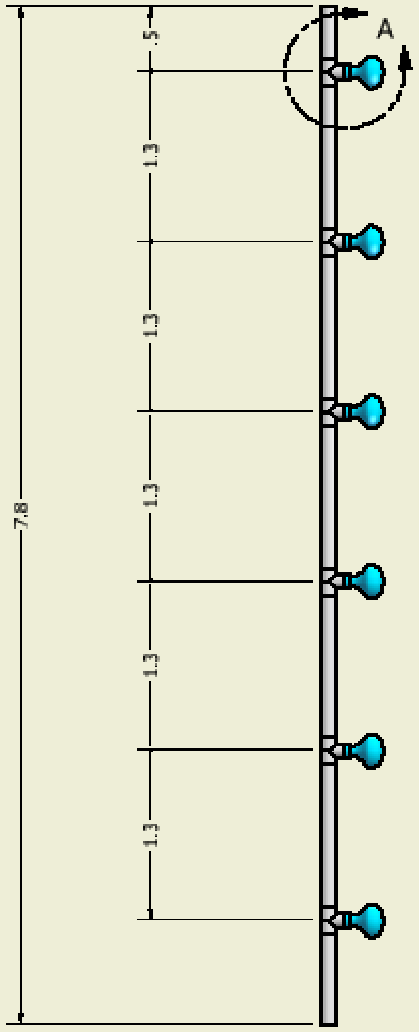


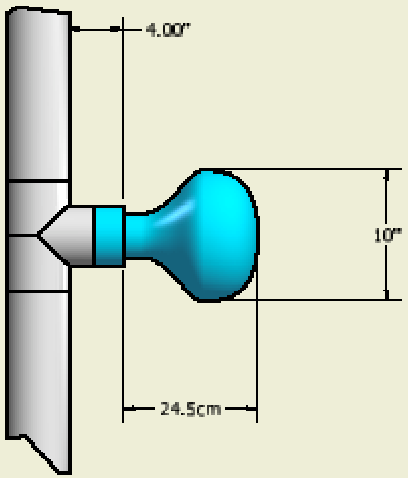




-Instrument the water pit (to be built) at Chooz near detector site.
-Initially not planned to be instrumented.
-Use PMTs identical to those considered for LBNE WC.
-One gets a small (240 ton) Water Cherenkov detector.

-Implementation: pack electronics in transmit signals through the PVC tube (air).





DETAIL A
SCALE 0.12 : 1

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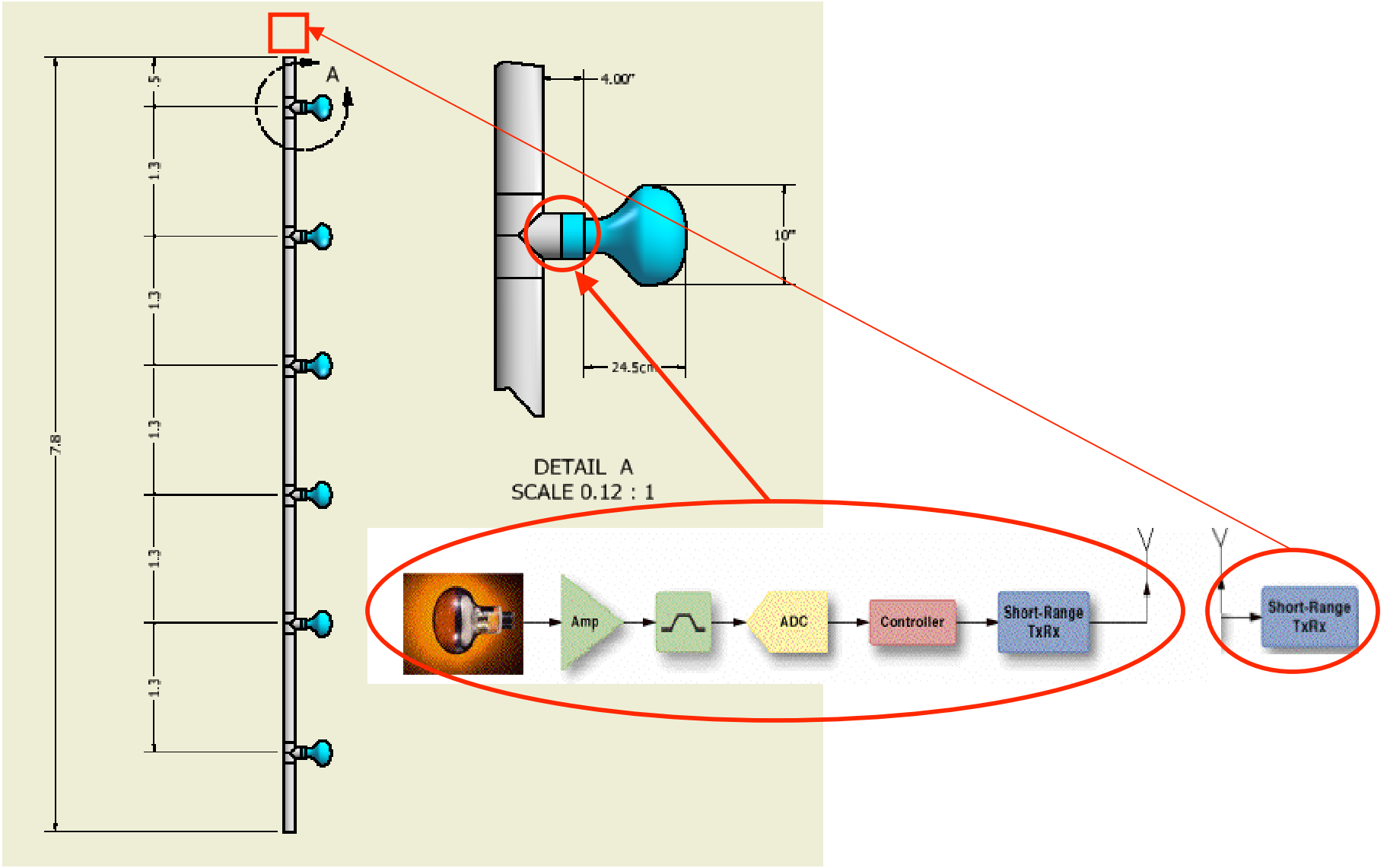

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